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(54) Reflective type liquid crystal display device.

(57) An optical phase compensating member (14) is disposed between the polarizer (15) and the liquid crystal cell (3,8,13) comprising a reflecting substrate (8) possessing smooth undulations and a reflecting film (7) forming a counter electrode.

The director of the liquid crystal molecules is oriented almost orthogonally to the slow axis of the optical compensator (14) whereas the axis of the polarizer (15) is oriented to 30° to 60° to the director direction.

By varying the electric field applied to the liquid crystal layer (13), the light shielding state is selected when the retardation $\Delta n_1 d_1$ of the liquid crystal layer (13) and the retardation $\Delta n_2 d_2$ of the optical compensator (14) are in the relation
$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = 0.25 + m/2 \pm 0.1$ (m=0, 1, 2, —), whereas the light transmitting state is selected when they are in the relation
$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = m/2 \pm 0.1$ (m=0, 1, 2,—), and these two states are used to present a display.

Fig. 1
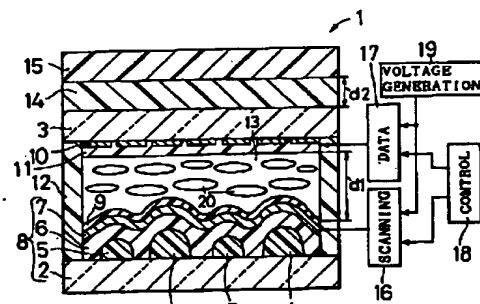
EP 0 576 303 A1

The present invention relates to a reflective type liquid crystal display device not using a backlight of direct viewing type, and mor particularly to a reflective type liquid crystal display device preferably used in office automation appliances such as word processors and so-called notebook type personal computers, video appliances, games machines, and the like.

Recently, the application of liquid crystal display devices has rapidly promoted in the word processor, laptop personal computer, and other office automation appliance markets, as well as the pocket-size television and other video appliance markets, etc. Among these liquid crystal display devices, the reflective type liquid crystal display device (for displaying by reflecting the light entering from outside) is particularly noticed for the possibility of lower power consumption, thinner thickness and lighter weight because it does not require a backlight as a light source.

Hitherto, in the reflective type liquid crystal display device, twisted nematic (TN) type and supertwisted nematic (STN) type liquid crystal have been employed.

In the TN type, a liquid crystal cell is disposed in a set of polarizers, and monochromatic (black and white) display is made by making use of the optical characteristics of the liquid crystal cell, that is, the optical rotatory when no voltage is applied and the canceling optical rotatory when voltage is applied.

For color display, a back light is mounted on the back side, and color filters of red, blue and green, for example, are installed in the liquid crystal cell, and multi-color display of a relatively small number of colors is achieved by additive color mixture by utilizing the light switching characteristics of the liquid crystal cell by no-application/application of voltage, or full color display capable of displaying any desired color in principle is realized.

The drive system of such reflective type liquid crystal display devices is generally an active matrix drive system or simple matrix drive system, which is employed in the display device of, for example, portable pocket-size liquid crystal televisions.

The display method widely employed in the display devices for office automation appliances such as word processors is, for example, the STN type for setting the twist angle of the liquid crystal molecules in a range of 180° to 270°, in a liquid crystal display structure similar to the TN type.

It is a feature of this STN type that electro-optical characteristics possessing a sharp threshold value can be realized by increasing the twist angle of the liquid crystal molecules to more than 90°, optimizing the setting angle of the transmission axis of the polarizer so that elliptical polarization occurs due to the birefring nce of the liquid crystal cell, and reflecting the sudden mol cular orientation deformation accompanying application of voltage to the birefringence changes of the liquid crystal. It is therefore suited to the simple matrix drive system.

On th th r hand, th shortcoming of this STN type is that the background color of display is tinted with yellowish green or dark blue due to the birefringence of the liquid crystal s. As an improving measure, a new liquid crystal display device is proposed, in which color is compensated by overlapping the STN panel for display with a panel for optical compensation or phase difference plate composed of polycarbonate or other high polymers, so that a display close to a monochromatic display is realized.

At present, the liquid crystal cell structure with such color compensation is distributed on market as the paper-white type liquid crystal display device.

Incidentally, the detailed principle of operation of the TN type and STN type is described in the "Liquid Crystal Device Handbook" compiled by Committee 142 of Japan Society for the Promotion of Science, 1989, pp. 329-346.

To realize these liquid crystal cells of TN type or STN type as reflective type liquid crystal display devices, in a structure in which the liquid crystal cell is held by a pair of polarizers, the reflector plate must be disposed at the outer side, owing to the restrictions of the principle of the display method.

Accordingly, owing to the thickness of the glass substrate used in the liquid crystal display device, parallax is caused depending on the angle of the user observing the glass substrate, that is, the angle formed by the normal direction of the glass substrate and the direction of the user observing the liquid crystal display device, and the display is recognized as double images.

Or, if the method of controlling the birefringence of the liquid crystals by electric field and displaying by utilizing the light shutter function, such as the conventional TN type and STN type, is applied in the reflective type display device directly by a single polarizer, monochromatic display with contrast cannot be realized owing to its own principle.

A liquid crystal display device of reflective TN (45° twisted) type using one polarizer and a 1/4 wavelength plate is disclosed in the Japanese Laid-open Patent Sho. 55-48733. In this device, using a 45° twisted liquid crystal layer, the plane of polarization is realized in two states, parallel to and 45° to the optical axis of the 1/4 wavelength plate by controlling the applied electric field, therefore realizing a monochromatic display. The liquid crystal cell is composed of, sequentially from the incident light side, a polarizer, a 45° twisted liquid crystal cell, a 1/4 wavelength plate, and a reflector.

Furthermore, the U.S.P. 4,701,028 (Clerc et al.) discloses a liquid crystal display device of reflective type perpendicular orientation type combining one polarizer, a 1/4 wavelength plate, and a perpendicular oriented liquid crystal cell.

The present applicants also filed an application

relating to a reflective type parallel orientation system by combining one polarizer, a parall l riented liquid crystal cell, and a phase difference plate.

In the liquid crystal display device disclosed in the Japanese Laid-open Patent Sho. 55-48733, however, since it is necessary to install a 1/4 wavelength plate between the liquid crystal layer and reflector, a reflective film cannot be composed, structurally, inside of the liquid crystal display device. In addition, the basic principle is the same as that for the TN type, and the steepness of the electro-optical characteristic is the same as for the TN type. Therefore, the contrast is low, and the steepness of the electro-optical characteristic is dull.

In the perpendicular oriented liquid crystal display device disclosed in the U.S.P. 4,701,028, (1) perpendicular orientation, in particular, slant perpendicular orientation is extremely difficult to control, and is not suited to mass production, (2) perpendicular orientation is weak in the orientation controlling force, and the response speed is slow, and (3) dynamic scattering may occur in perpendicular orientation when driving and hence the reliability is low, and other problems are known.

In the reflective type parallel orientation system, the display characteristic is inferior unless the setting angle of the director of the polarizer, phase difference plate, and liquid crystal molecule is appropriate, and coloring may occur due to wavelength dispersion of the liquid crystal cell and phase difference plate. Furthermore, when the reflector is directly installed at the liquid crystal layer side, the steepness of electro-optical characteristics is worsened due to undulations of the reflector.

It is hence a primary object of the invention to present a reflective type liquid crystal display device of high sharpness and high display quality, without parallax, capable of solving the technical problems.

To achieve the above object, the invention presents a reflective type liquid crystal display device disposing a polarizer at the incident side of light of liquid crystal cell,

the liquid crystal cell comprising:

an insulating substrate forming at least a transparent electrode,

a mirror-finished light reflecting member possessing smooth undulations on one surface, and forming a light reflecting surface on the same surface, and forming a counter electrode for displaying and driving through collaboration with the transparent electrode, and

a liquid crystal layer having the orientation of liquid crystal molecules selected in either parallel orientation or twisted orientation, being sealed in betwe n the insulating substrate and the light reflecting member,

wherein an optical phase compensating member is disposed between the polarizer and the liquid crystal cell.

In th inv nti n, the light transmis ion state is selected when the retardation $\Delta n_1 d_1$ (Δn_1: optical anisotropy of liquid crystal layer, d_1: thickness of liquid crystal layer) of the liquid crystal cell, and the retardation $\Delta n_2 d_2$ (Δn_2: optical anisotropy of optical phase compensating member, d_2: thickness of optical phase compensating member) of the optical phase compensating member are in the relation of

$$|\Delta n_1 d_1 - \Delta n_2 d_2| / \lambda = m/2 \pm 0.1 \ (m = 0, 1, 2, \cdots) \quad (1)$$

in terms of the wavelength λ in a range of 400 to 700 nm upon application of voltage V1, and the light shielding state is selected when they are in the relation of

$$|\Delta n_1 d_1 - \Delta n_2 d_2| / \lambda = 0.25 + m/2 \pm 0.1 \ (m = 0, 1, 2, \cdots) \quad (2)$$

in terms of the wavelength λ in a range of 400 to 700 nm upon application of voltage V2, and the numerical value of $|\Delta n_1 d_1 - \Delta n_2 d_2| / \lambda$ is varied depending on the electric field applied to the liquid crystal layer.

Also, in the invention, the retardation $\Delta n_1 d_1$ of the liquid crystal cell and the retardation $\Delta n_2 d_2$ of the optical phase compensating member are selected so as to satisfy formula (1) in terms of the wavelength λ of the light in a range of 400 to 700 nm upon non-application of voltage, and the numerical value of $|\Delta n_1 d_1 - \Delta n_2 d_2| / \lambda$ is varied depending on the electric field applied to the liquid crystal layer.

In the invention, moreover, the retardation $\Delta n_1 d_1$ of the liquid crystal cell and the retardation $\Delta n_2 d_2$ of the optical phase compensating member are selected so as to satisfy formula (2) in terms of the wavelength λ of the light in a range of 400 to 700 nm upon non-application of voltage, and the numerical value of $|\Delta n_1 d_1 - \Delta n_2 d_2| / \lambda$ is varied depending on the electric field applied to the liquid crystal layer.

In the invention, the light reflecting film forming the light reflecting surface of the light reflecting member confronts the liquid crystal layer side.

In the invention, the light reflecting surface is determined as an electrode surface confronting the transparent electrode formed on the insulating substrate.

In the invention, the optical phase compensating member is a liquid crystal cell comprising a pair of transparent substrates, transparent electrodes formed on the transparent substrates, and a liquid crystal layer inserted between the transparent substrates.

Also in the invention, the optical phase compensating member is a high molecular oriented film.

According to the invention, a transparent flattened layer for absorbing the undulations formed on the surface of the light reflecting member is disposed on the light reflecting surface, and transparent electrodes are formed on this flattened layer, and these transparent electrodes are determined as th electrodes confronting the transparent lectrodes formed on

the insulating substrate.

In the inventi n, a color filter layer is formed on either th insulating substrate r the transparent electrode formed on the insulating substrate.

The display principle of the reflective type liquid crystal display device of the invention is explained below. The incident light into the reflective type liquid crystal display device of the invention reaches the reflecting member through the polarizer, optical phase compensating member, and liquid crystal layer, and is reflected by the reflecting member, and is emitted through the liquid crystal layer, optical phase compensating member, and polarizer. Herein, when the linear polarized light obtained from the polarizer passes through the optical compensating member and liquid crystal layer, and then becomes elliptical polarized light, and the phase difference δ of the elliptical polarized light at this time is expressed as

$$\delta = (2\pi/\lambda)(\Delta n_1 d_1 - \Delta n_2 d_2) \quad (3)$$

where the symbol λ, denotes the wavelength of light, $\Delta n_1 d_1$ is the retardation of liquid crystal layer, $\Delta n_2 d_2$ is the retardation of optical phase compensating member, Δn_1, Δn_2 are optical anisotropies (birefringences) of liquid crystal layer and optical phase compensating member, respectively and d_1, d_2 denote the thicknesses of the liquid crystal layer and the optical phase compensating member respectively.

When the value of δ in formula (3) is set in the so-called 1/4 wavelength condition and 3/4 wavelength condition, the incident light is cut off. That is, these conditions are generally expressed as the establishment of the formula $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = 0.25 + m/2$ shown in formula (2). Considering the wavelength dispersion of retardation of the liquid crystal layer, the characteristics of the optical phase compensating member may be set so as to roughly satisfy formula (2) in the wavelength range of 400 to 700 nm, that is, within the visible wavelength range.

The linear polarized light from the polarizer entering the optical phase compensating member passes through the optical phase compensating member and liquid crystal layer satisfying formula (2), and becomes, for example, clockwise circular polarized light, which is reflected by the reflecting member and becomes a counterclockwise circular polarized light. On the other hand, when becoming counterclockwise circular polarized light by passing through the liquid crystal, it is reflected by the reflecting member to become clockwise circular polarized light.

Hence, as the reflected light from the reflecting member passes through the liquid crystal layer and optical compensating member, it becomes linear polarized light orthogonal to the linear polarized light before passing through the liquid crystal layer at the time of input, and is cut off by the polarizer.

When the optical phase compensating member satisfies the conditions of optical anisotropy Δn_2 and thickness d_2 s as to satisfy formula (1) $|\Delta n_1 d_1 -$

$\Delta n_2 d_2|/\lambda = m/2$ polarized light entering th optical phase compensating member through the polarizer remains linear polarized light parallel in the direction of polarization even after passing through the optical phase compensating member and liquid crystal layer, and therefore after reflection by the reflecting member or after the reflected light passes again through the liquid crystal layer and optical phase compensating member, the same state of polarization of the linear polarized light parallel in the direction of polarization is maintained. Therefore, the exit light passes through the polarizer. Display is made by making use of these light shielding and transmitting states.

In such a principle of display, if the light reflecting member does not maintain the polarizing performance, conversion from clockwise circular polarized light to counterclockwise circular polarized light or inverse conversion is not done efficiently, and the contrast is lowered.

As a reflecting member maintaining the polarizing performance, a flat mirror-surface reflecting member is known, but since the external object is directly reflected thereon, it is hard to observe the display. The present applicant has already filed a patent application for a fabrication method of reflecting plate. In this patent application, a photosensitive resin is applied and formed on a substrate, and it is further treated to deform the protruding portions into a smooth shape, and a reflection plane is formed thereon. According to this method, the protruding portions may be smoothly formed, and multiple reflection occurs rarely, so that a bright reflection plane maintaining the polarizing performance is obtained. By using such a reflecting member, a reflecting plate having both mirror smoothness or polarizing performance and diffusion property may be obtained.

Thus, according to the invention, the incident light reaches the reflecting member through the polarizer, optical phase compensating member, and liquid crystal layer, and is reflected by the reflecting member to be emitted through the liquid crystal layer, optical phase compensating member, and polarizer. The linear polarized light obtained through the polarizer passes through the optical compensating member and liquid crystal layer, and becomes elliptical polarized light, and the phase difference δ of this elliptical polarized light is determined in formula (1).

By adjusting the numerical value $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda$ in formula (1) by the electric field applied to the liquid crystal layer, a light switching action can be realized. That is, the light reflecting member is composed inside of the liquid crystal cell, and the protruding portions on the undulations of the reflection plane of the light reflecting member may be formed smoothly, so that a bright reflection plane with few multiple reflections and maintainance of the polarizing property may be realized. By using such reflecting member, the reflector having both polarizing properti s and

diffusion properties is obtained. That is, the parallax can be eliminat d, and a reflective type liquid crystal display device of high sharpness and high display quality is realized.

Besides, by parallel orientation or twisted orientation of the liquid crystal molecule, a reflective type liquid crystal display device high in response speed, superior in reliability of display action, and suited to mass production is realized.

The invention moreover provides a reflective type liquid crystal display device comprising an insulating substrate forming at least a transparent electrode, a reflector possessing smoothly and continuously changing undulations on one side and forming by thin film possessing, a light reflection function on the same surface, a liquid crystal cell possessing a liquid crystal layer inserted between the insulating substrate and reflector, a polarizer disposed at the light incident side, and a substrate possessing an optical phase compensating function being disposed between the polarizer and liquid crystal cell, wherein

the director direction of the liquid crystal molecules of the liquid crystal cell is almost orthogonal to the slow direction of the substrate possessing the optical phase compensating function,

the value of $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda$, is varied by the electric field applied to the liquid crystal layer so as to establish the light shielding state when the retardation $\Delta n_1 d_1$ of the liquid crystal cell and the retardation $\Delta n_2 d_2$ of the substrate possessing the optical phase compensating function satisfy the formula (2), and

the light transmitting state when they satisfy the formula (1), thereby displaying by making use of these two states, and moreover the absorption axis or transmission axis of the polarizer is set in a range of 30° to 60° to the director direction of the liquid crystal molecule of the liquid crystal cell.

In the invention, the light shielding state is obtained when the retardation $\Delta n_1 d_1$ of the liquid crystal cell and the retardation $\Delta n_2 d_2$ of the substrate possessing the optical phase compensating function satisfy the formula (2) for a certain wavelength λ in a range of 400 to 700 nm when voltage $V_1(V_1 \geqq 0)$ is applied, and the light transmitting state is obtained when they satisfy the formula (1) for a certain wavelength λ in a range of 400 to 700 nm when voltage $V_2(V_2 > V_1)$ is applied,

the relation is $(\Delta n \lambda)_F > (\Delta n \lambda)_{LC}$ when the magnitude $(\Delta n \lambda)_F$ of wavelength dispersion of the substrate possessing the optical phase compensating function and the magnitude $(\Delta n \lambda)_{LC}$ of wavelength dispersion of the liquid crystal cell satisfy the condition of $\Delta n_1 d_1 > \Delta n_2 d_2$ in the light shielding state, and

it is $(\Delta n \lambda)_F < (\Delta n \lambda)_{LC}$ when satisfying the condition of $\Delta n_1 d_1 < \Delta n_2 d_2$ in the light shielding state.

Also in the invention, th light transmitting state is btained when the retardati n $\Delta n_1 d_1$ of th liquid crystal cell and the retardation $\Delta n_2 d_2$ of the substrate

possessing the optical phase compensating function satisfy th formula (1) for a certain wavelength in a range of 400 to 700 nm when voltage $V_1(V_1 \geqq 0)$ is applied, and the light shielding state when they satisfy the formula (2) for a certain wavelength in a range of 400 to 700 nm when voltage $V_2(V_2 > V_1)$ is applied,

the relation is $(\Delta n \lambda)_F > (\Delta n \lambda)_{LC}$ when the magnitude $(\Delta n \lambda)_F$ of wavelength dispersion of the substrate possessing the optical phase compensating function and the magnitude $(\Delta n \lambda)_{LC}$ of wavelength dispersion of the liquid crystal cell satisfy the condition of $\Delta n_1 d_1 > \Delta n_2 d_2$ in the light shielding state, and

it is $(\Delta n \lambda)_F < (\Delta n \lambda)_{LC}$ when satisfying the condition of $\Delta n_1 d_1 < \Delta n_2 d_2$ in the light shielding state.

In the invention, the reflective film forming plane of the reflector is disposed at the liquid crystal layer side.

In the invention, the thin film possessed light reflecting function of the reflector functions also as the electrode confronting the transparent electrode formed on the insulating substrate.

In the invention, a transparent flattened layer for absorbing undulations is provided on the thin film possessing the light reflecting function, and a transparent electrode is formed thereon so as to function as the electrode confronting the electrode formed on the insulating substrate.

In the invention, a color filter layer is formed on the insulating substrate or transparent electrode.

The principle of display of the reflective type liquid crystal display device of the invention is described below. Fig. 6 is an operation explanatory diagram of the operation of the reflective type liquid crystal display device of the invention.

The incident light to the reflective type liquid crystal display device of the invention passes through the polarizer 15, optical phase compensator 14, and liquid crystal layer 13, and is reflected by the reflector 8, and passes through the liquid crystal layer 13, optical phase compensator 14, and polarizer 15 to be emitted. The linear polarized light obtained from the polarizer 15 passes through the optical phase compensator 14 and liquid crystal layer 13, and then becomes elliptical polarized light. At this time, the phase difference δ of the elliptical polarized light is expressed as follows.

$$\delta = (2\pi/\lambda)(\Delta n_1 d_1 - \Delta n_2 d_2) \quad (3)$$

where λ is the wavelength, $\Delta n_1 d_1$ is the retardation of liquid crystal layer, $\Delta n_2 d_2$ is the retardation of optical phase compensator, Δn_1, Δn_2 are optical anisotropies (birefringences) of the liquid crystal layer and optical phase compensator respectively, and d_1, d_2 are thicknesses of the liquid crystal layer and optical phase compensator respectively.

When the value δ in the formula (3) is set in the so-called 1/4 wav l ngth condition and 3/4 wavelength condition, the incident light is cut off. Generally, the condition is expressed as the establishment of

$$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = 0.25 + m/2 \quad (m = 0, 1, 2, \cdots)$$
$$(4)$$

and therefore th incident light is cut off when the value δ in the formula (3) is so set as to satisfy the formula (4).

More specifically, the incident linear polarized light passes through the optical phase compensator 14 and liquid crystal layer 13 satisfying the specified condition to be, for example, a clockwise circular polarized light, and is reflected by the reflector to be a counterclockwise circular polarized light. To the contrary, when a counterclockwise circular polarized light enters, a clockwise circular polarized light is obtained.

Consequently, passing again through the liquid crystal layer 13 and optical phase compensator 14, it becomes linear polarized light orthogonal to the linear polarized light which originally passed through the polarizer, and so is cut off by the polarizer. Besides, when satisfying

$$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = m/2 \quad (m = 0, 1, 2, \cdots) \quad (5)$$

the incident linear polarized light is emitted in the same polarization plane even after passing through the liquid crystal layer 13, and the light passes through the polarizer 15. Therefore, display is made by making use of these two states.

Actually, the light shielding state and light transmitting state are not always required to satisfy the conditions of the formula (4) and formula (5), and it is practically enough for the light shielding state satisfies the formula (2) and the light transmitting state satisfies the formula (1).

In this principle of display, if the light reflector does not possess polarizing properties, conversion from clockwise circular polarized light to counterclockwise polarized light or its inverse conversion is not done efficiently, and the contrast is lowered.

As a reflecting member maintaining the polarizing performance, a flat mirror-surface reflecting member is known, but since the external object is directly reflected thereon, it is hard to observe the display. The present applicant has already filed a patenttapplication for a fabrication method of reflecting plate. In this patent application, a photosensitive resin is applied and formed on a substrate, and it is further treated to deform the protruding portions into a smooth shape, and a reflection plane is formed thereon.

According to this method, the protruding portions may be smoothly formed, and multiple reflection occurs rarely, so that a bright reflection plane nearly maintaining the polarizing performance is obtained. By using such reflecting member, a reflecting plate having both mirror smoothness or polarizing performance and diffusion property may be obtained.

Moreover, in the light shielding state wh n voltage $V_1(V_1 \geqq 0)$ is applied and in the light transmitting state when voltage $V_2(V_2 > V_1)$ is applied, the formula (4) may be satisfied for a wide rang of wavelengths

by satisfying $(\Delta n\lambda)_F > (\Delta n\lambda)_{LC}$ when $\Delta n_1 d_1 > \Delta n_2 d_2$ in th light shielding state r $(\Delta n\lambda)_F < (\Delta n\lambda)_{LC}$ when $\Delta n_1 d_1 < \Delta n_2 d_2$ in the light shielding state.

Likewise, in the light transmitting state when voltage $V_1(V_1 \geqq 0)$ is applied and in the light shielding state when voltage $V_2(V_2 > V_1)$ is applied, the formula (4) may be satisfied for a wide range of wavelengths by satisfying $(\Delta n\lambda)_F > (\Delta n\lambda)_{LC}$ when $\Delta n_1 d_1 > \Delta n_2 d_2$ lin the light shielding state or $(\Delta n\lambda)_F < (\Delta n\lambda)_{LC}$ when $\Delta n_1 d_1 < \Delta n_2 d_2$.

That is, the wavelength dispersion of the smaller retardation in the light shielding state is set larger than the other wavelength dispersion. As a result, the wavelength dispersions of the liquid crystal cell and the substrate possessing the optical phase compensating function cancel each other in the light shielding state, so that an excellent display of high contrast is obtained.

According to the reflective type liquid crystal display device of the invention, the reflecting member may be disposed at the liquid crystal layer side, and the light is cut off efficiently by defining $\phi = 30°$ to $60°$, and furthermore in the light shielding state, by adjusting the wavelength dispersion of the liquid crystal layer and optical phase compensating member, the condition of the light shielding state can be satisfied in a wavelength region of a much wider range than in the conventional phase difference plate, so that a reflective type liquid crystal display device of no parallax, high contrast, high definition, and high display quality is realized.

Other and further objects, features, and advantages of the invention will be more explicit from the following detailed description taken with reference to the drawings wherein:

Fig. 1 is a sectional view of a liquid crystal display device 1 according to an embodiment of the invention;

Fig. 2 is a plan of a glass substrate 2;

Fig. 3 is a diagram explaining the optical characteristics of the liquid crystal display device 1;

Fig. 4 (1)–(5) are sectional view explaining the manufacturing process of a reflector 8;

Fig. 5 is a graph explaining the voltage-reflectivity characteristics of the liquid crystal display device 1;

Fig. 6 (1), (2) are diagrams explaining the display action of the liquid crystal display device 1 of the same embodiment;

Fig. 7 is an optical characteristic explanatory diagram of a liquid crystal display device in a second embodiment of the invention;

Fig. 8 is a diagram showing the voltage dependence of reflectivity of a reflective type liquid crystal display device of the invention;

Fig. 9 (a),(b),(c) are principle explanatory diagram of another embodiment of the invention;

Fig. 10 (a),(b),(c),(d) are principle explanatory di-

agrams of a different mbodiment of the inven-
ti n;
Fig. 11 is a diagram showing the characteristics
of Δnd/λ when using the phase difference plate of
the invention and when using a conventional
phase difference plate; and
Fig. 12 is a diagram showing the voltage depend-
ence of reflectivity of a reflective type liquid crys-
tal display device in another different embodi-
ment.

Now referring to the drawing, preferred embodi-
ments of the invention are described below.

Fig. 1 is a sectional view of a reflective type liquid
crystal display device (hereinafter called liquid crystal
display device) 1 in an embodiment of the invention,
and Fig. 2 is a plan of a glass substrate 2 in the liquid
crystal display device 1. The liquid crystal display de-
vice 1 of the embodiment is, for example, of simple
matrix type. The liquid crystal display device 1 pos-
sesses a pair of transparent glass substrates 2, 3,
many large bumps 4 and small bumps 5 made of syn-
thetic resin material described later are formed on the
glass substrate 2. The bottom diameters D1, D2 of
large bumps 4 and small bumps 5 are defined, for ex-
ample, as 5 μm and 3 μm, and their interval D3 is de-
fined, for example, as 2 μm or more.

To cover these bumps 4, 5 and fill the gaps
among bumps 4, 5, a smoothing film 6 is formed. The
surface of the smoothing film 6 is formed as a smooth
curvature due to the effects of the bumps 4, 5. On the
smoothing film 6, a reflective metal film 7 made of
metal material such as aluminum, nickel, chromium or
silver is formed. The reflective metal film 7 is formed
in plural rows in a longitudinal band form in the lateral
direction as shown in Fig. 2. The bumps 4, 5, smooth-
ing film 6 and reflective metal film 7 on the glass sub-
strate 2 compose a reflector 8 which is a light reflect-
ing member. An orientation film 9 is formed on the re-
flective metal film 7.

On the surface of the glass substrate 3 confront-
ing the glass substrate 2, transparent electrodes 10
made of ITO (Indium tin oxide) or the like are formed
in plural rows, in a longitudinal band form in the direc-
tion orthogonal to the longitudinal direction of the re-
flective metal film 7. The reflective metal film 7 and
transparent electrodes 10 are combined to compose
a matrix electrode structure. Covering the glass sub-
strate 3 on which the transparent electrodes 10 are
formed, an orientation film 11 is formed, and the per-
ipheral margin of the mutually confronting glass sub-
strates 2, 3 is sealed with a sealing material 12. Be-
tween the orientation films 9, 11, a liquid crystal layer
13, for example, a liquid crystal material of which di-
electric anisotropy Δε is positive, such as tradename
ZLI4792, ZLI2973 of Merck, is inserted.

On the opposite side of the liquid crystal layer 13
of the glass substrate 3, an optical compensating
plate 14 which is an optical phase compensating

member made of polycarbonate oriented film (optical
anisotropy Δn₂, thickness d₂) is provid d, and a polar-
izer 15 with single transmissivity of 48% is disposed
thereon.

A scanning circuit 16 and a data circuit 17 are
connected to the reflective metal film 7 and transpar-
ent electrode 10. The scanning circuit 16 and data cir-
cuit 17 realize display by applying display voltage V1
or non-display voltage V2 from a voltage generating
circuit 19, while scanning the reflective metal film 7
and transparent electrode 10 on the basis of the dis-
play data corresponding to the display content, by the
control of a control circuit 18 such as microprocessor.

Fig. 3 is a diagram showing an optical composi-
tion of polarizer 15, optical compensator 14 and liquid
crystal layer 13. That is, to the axial direction L1 of the
absorption axis or transmission axis of the polarizer
15, the angle θ1 of the axial direction L2 of the slow
direction of the optical compensator 14 in the clock-
wise direction is defined, for example, at 45°. On the
other hand, the angle θ2 of the orientation direction
L3 of the liquid crystal molecule 20 of the liquid crys-
tal layer 13 shown in Fig. 1 to the axial direction L1 in
the counterclockwise direction is defined, for exam-
ple, at 45°.

Fig. 4 is a sectional view explaining the manufac-
turing process of the reflector 8 shown in Fig. 1. As
shown in Fig. 4 (1), in this embodiment, a glass sub-
strate 2 (tradename 7059 of Corning) of thickness t1
(for example, 1.1 mm) is used. On the glass substrate
2, for example, a photosensitive resin material such
as tradename OFPR-800 of Tokyo Okasha is applied
by spin coating at 500 to 3000 rpm. and a resist film
21 is formed. In this embodiment, preferably, by spin
coating for 30 seconds at 2500 rpm, the resist film 21
is formed of thickness t2 (for example, 1.5 μm).

Consequently, the glass substrate 2 on which the
resist film 21 is formed is baked for 30 minutes at
90°C, and then, as shown in Fig. 4 (2), it is exposed
by placing a photo mask 22 forming multiple circular
patterns of two types of large and small size descri-
bed below, and is developed in a developing solution
composed of a 2.38% solution of, for example, trade-
name NMD-3 of Tokyo Okasha, and large bumps 23
and small bumps 24 at different heights are formed on
the surface of the glass substrate 2 as shown in Fig.
4 (3). The reason of forming bumps of two or more
types differing in height is intended to prevent color-
ing of reflected light due to interference of light reflect-
ed by the tops and bottoms of the bumps.

The photo mask 22 is a random configuration of
circles of diameter D1 (for example, 5 μm) and diam-
eter D2 (for example, 3 μm) as shown in the layout of
large bumps 4 and small bumps 5 in Fig. 2, and the
interval D3 of the circles is defined to be at least 2 μm
or more. The pattern of the photo mask 22 is not lim-
ited to this. The glass substrate 2 in the manufactur-
ing stage in Fig. 4 (3) is heated for an hour at 200°C,

and the tops of the bumps 23, 24 are slightly melted to form in an arc profile as shown in Fig. 4 (4). Furthermore, as shown in Fig. 4 (5), n the glass substrate 2 in the manufacturing stage in Fig. 4 (4), the same material as the photosensitive resin material is applied by spin coating at 1000 to 3000 rpm. In this embodiment, preferably, it is applied by spin coating at 2000 rpm. As a result, the recesses among bumps 23, 24 are filled up, and the formed surface of the smoothing film 6 can be formed into a relatively moderate and smooth curvature. In the embodiment, as the smoothing film 7, the same resin as the photosensitive resin material was applied, but different kinds may be used. In this case, the surface step was 0.7 μm.

Furthermore, on the surface of the smoothing film 6, a metal thin film of aluminum, nickel, chromium or silver is formed to a thickness of t3 (for example, 0.01-1.0 μm). In this embodiment, by sputtering aluminum, the reflective metal film 7 is formed. As a result, the reflector 8 is completed.

A polyimide resin film is formed on the glass substrates 2, 3, and is baked for an hour at 200°C. Afterwards, rubbing is applied to orient the liquid crystal molecules 20. Thus, orientation films 9, 11 are formed. The sealing material 12 for sealing between these glass substrates 2, 3 is formed by screen printing an adhesive seal material containing a spacer in a diameter of, for example, 6 μm.

When combining thus formed reflector 8 and the glass substrate 3 on which the transparent electrodes 10 and orientation film 11 are formed, a spacer of diameter of 5.5 μm is directly applied between the glass substrates 2 and 3, and the thickness of the liquid crystal layer is defined. The liquid crystal layer 13 is adhered with the seal material 12, with the glass substrates 2, 3 facing each other, and is evacuated and sealed. The refractive index anisotropy Δn_1 of the liquid crystal layer 13 is 0.094, and the layer thickness d_1 is, for example, 5.5 μm, and therefore the retardation $\Delta n_1 d_1$ of this liquid crystal layer 13 is 517 nm.

Fig. 5 is a graph showing the voltage/reflectivity characteristics of the liquid crystal display device 1 of the embodiment. In order to achieve the numerical value $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda = 0.25$, 0.3, 0.5 upon input of light with the wavelength λ of 550 nm, the retardation $\Delta n_2 d_2$ of the optical compensator 14 is selected. In the case of each numerical value, the characteristic curves 25, 26, 27 in Fig. 5 are obtained. That is, the characteristic curve 25 corresponds to the case of m = 0 in the formula (2), and the characteristic curve 27, to the case of m = 1 in the formula (1).

The characteristic curve 26 satisfies neither formula (1) nor formula (2), and exhibits an intermediate state between the characteristic curve 27 in which the reflected light from the reflector 8 is emitted from the liquid crystal display device 1 when no voltag is applied, and the characteristic curve 25 in which the

reflected light is cut off, and satisfies either formula (1) or f rmula (2) when the voltag is V1, or the ther ne f formula (1) or formula (2) when the v ltage is V2, realizing a favorable display quality at this time. That is, in this embodiment, by selecting the retardation of the optical compensator 14 or liquid crystal layer 13 in order that the formula (1) and formula (2) may be satisfied, a high display quality is realized.

According to the experiment by the present inventor relating to this embodiment, when a voltage was applied, the reflectivity in the normal direction to the light entering from a direction inclined by 30° from the normal direction of the liquid crystal display device 1 was about 45% at maximum, and the maximum contrast ratio was 7. As the reference material for determining the contrast ratio at this time, a standard white plate of magnesium oxide MgO was used. Incidentally, in the graph shown in Fig. 5 it is when the numerical value $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda$ is ±0.25 that the reflectivity is lowered, and the maximum reflectivity is achieved when the numerical value $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda$ is 0, 0.5. By using these two states, a monochromatic display is realized.

The embodiment related to the case of m = 1 in formula (1) and m = 0 in formula (2) only, but similar effects were confirmed if the variable m was other values. Meanwhile, in both formula (1) and formula (2), the effect is expressed when the difference of retardation between the liquid crystal layer and film shows a specific value, but actually this value varies depending on the fluctuations of the thickness of liquid crystal film and thickness of film. Accordingly, effects of fluctuations of these values on the contrast were studied, but there was no serious effect in a range of ±0.1 or less in either formula (1) or formula (2), and it was found to be sufficiently practicable.

Fig. 6 is a diagram explaining the action of the liquid crystal display device 1 of the embodiment, in which the liquid crystal display device 1 is shown in a disassembled state for the convenience of explanation. In the light shielding action shown in Fig. 6 (1), when the incident light 28 passes through the Polarizer 15, it becomes a linear polarized light 29 parallel to the axial direction L1 of the polarizer 15. The linear polarized light 29 passes through the optical compensator 14 and liquid crystal layer 13 satisfying the formula (2), and becomes, for example, a clockwise circular polarized light 30. This circular polarized light 30 is reflected by the reflector 8 to be a counterclockwise circular polarized light 31. When this circular polarized light 31 passes through the liquid crystal layer 13 and optical compensator 14 possessing the retardations satisfying the formula (2), it becomes a linear polarized light 32 possessing a polarization plane in the direction orthogonal to the direction of the linear polarized light 29 at the time of the incidence. This linear polarized light 32 is cut off by the polarizer 15. That is, the reflected light from the reflector 8 is cut

off.

By contrast, in th light transmitting acti n shown in Fig. 6 (2), th retardations $\Delta n_2 d_2$, $\Delta n_1 d_1$ of the optical compensator 14 and liquid crystal layer 13 are selected so as to satisfy the formula (1). At this time, when the incident light 28 passes through the polarizer 15, it becomes linear polarized light 29 parallel to the axial direction L1. This linear polarized light 29, if passing through the optical compensator 14 and liquid crystal layer 13 determined to satisfy the formula (1), maintains the same polarized state. If the linear polarized light 29 passing through the liquid crystal layer 13 is reflected by the reflector 8, the same linear polarized state is maintained, and it is the same even after passing through the liquid crystal layer 13 and optical compensator 14. Therefore, this reflected light passes through the polarizer 15 and is emitted.

In this embodiment, as the optical compensator 14, a oriented film made of polycarbonate is used, but the invention is not limited to this alone, and other drawn films of, for example, polyvinyl alcohol (PVA) and polymethyl methacrylate (PMMA) may be also used. Further, a liquid crystal cell formed with orientation films on the surfaces of a pair of glass substrates, and with a liquid crystal layer injected between orientation films, to orient parallel, may be also used as an optical phase compensator. In this case, the retardation of the liquid crystal layer is also the value defined in the formula (1) and formula (2). The liquid crystal molecules are arranged so as to be orthogonal to the liquid crystal molecule of the display cell.

In the reflective type liquid crystal display device 1 of the invention. since the surface for forming the reflective metal film 7 of the reflector 8 is disposed at the liquid crystal layer 13 side, the parallax for observing the liquid crystal display device 1 may be eliminated, so that a favorable display screen may be obtained. In the case of the constitution in which the liquid crystal display device 1 is driven by an active matrix driving technique, when used as the pixel electrode connected to the nonlinear element in the thin film transistor or MIM (metal-insulating film-metal) structure used as a switching element, it is confirmed that an excellent display quality as mentioned above is realized.

Moreover, to increase the steepness of electro-optical characteristics, it is preferred that the retardation $\Delta n_1 d_1$ of the liquid crystal layer 13 be uniform regardless of the location. Strictly speaking, if the reflector 8 has undulations due to bumps 4, 5 as mentioned above, the film thickness of the liquid crystal layer 13 varies between the tops of the bumps 4, 5 and bottoms among the bumps 4, 5, and therefore the retardation varies. Accordingly, the present inventor added a flattened layer made of, for example, acrylic resin, for smoothing the surface by filling up the surface undulations of th reflective metal film 7 on the

reflective metal film 7 of the reflector 8 shown in Fig. 1, and forming the transparent electrodes such as ITO thereon in the same shape as the reflectiv metal film 7, thereby forming an electrode for display. Thus, the height difference of the bumps on the surface of the flattened layer may be defined within 0.1 μm.

By thus composing, the steepness of the electro-optical characteristics may be markedly enhanced. In this case, whether organic material or inorganic material, any transparent film having flattening capability may be used regardless of the material. Hence, it has been confirmed that simple multiplex driving of more than 100 scanning lines is possible.

Instead of the glass substrate 2 in the embodiment, it is confirmed that the same effects are exhibited also by transparent substrates such as silicon substrates. When using such silicon substrate as the glass substrate 2 in the embodiment, it is advantageous because the circuit elements such as the scanning circuit 16, data circuit 17, control circuit 18, and voltage generating circuit 19 may be formed by integrating on the silicon substrate.

In another embodiment of the invention. a nematic liquid crystal twisted 240° between the glass substrates 2 and 3 (for example, tradename SD-4107 of Chisso) may be used as the liquid crystal layer 13. In this embodiment, as the optical compensator 14 in the structure shown in Fig. 1, a orientation film of polycarbonate was used, and the retardations $\Delta n_1 d_1$, $\Delta n_2 d_2$ of the liquid crystal layer 13 and optical compensator 14 were adjusted so as to satisfy the conditions of the formula (1) and formula (2). The other constituent elements were the same as in the constitution shown in Fig. 1. In this constitution, according to the experiment by the inventor, the display contrast was 6 in the case of 1/200 duty cycle, and a favorable display characteristic free from parallax was realized.

In this embodiment, the liquid crystal layer 13 was a 240° twisted liquid crystal, but the invention is not limited to this alone, and the liquid crystal material of any twist angle, or liquid crystal material without twist may be used in the invention as far as it is a liquid crystal material possessing the characteristics capable of controlling the retardation by electric field. Besides, as the optical compensator 14, retardation can be set, and the invention may be realized by using a liquid crystal material capable of optimally setting the retardation so as to satisfy the conditions of the formula (1) and formula (2).

The invention is not limited to the foregoing embodiments alone, and may be applied in wider reflective type optical control devices. Moreover, by forming a color filter layer on one substrate, multi-color or full-color displays may be realized.

Fig. 7 shows the setting angles of slow direction (α) of the optical phase compensator 14, director (β) f the liquid crystal molecule f the liquid crystal layer 13, and the absorpti n axis or transmission axis (γ) of

the polarizer 15 in a second mbodiment of the invention. In this embodiment, as th liquid crystal material, tradename ZLI2973 of Merck was used.

The refractive index anisotropy Δn_1 of the liquid crystal used in the embodiment is 0.1626, and the cell thickness d is 5.5 μm, and hence the retardation $\Delta n_1 d_1$ of the liquid crystal layer 13 is 894 nm. The director of the liquid crystal molecule of the liquid crystal layer 13 and the slow direction of the optical phase compensator 14 are crossing orthogonally, and the angle φ formed by the absorption axis or transmission axis of the polarizer 15 and the director of the liquid crystal molecule is 15, 30, 45, 60, and 70°. The retardation $\Delta n_2 d_2$ of the optical phase .XQ215E compensator 14 was selected so as to be $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda = 0.25$ when the wavelength λ was 550 nm, and the voltage-reflectivity characteristics in the case of φ=15°, 30°, 45°, 60°, 75° were measured, of which results are shown in Fig. 8. That is, the characteristics in the case of φ=45°, 30°, 15° correspond to the characteristic curves a, b, c in Fig. 8. Incidentally, the characteristics at φ=60°, 75° were respectively almost the same as the characteristic curve b of φ=30°, and the characteristic curve c of φ=15°.

When a voltage was applied, the reflectivity in the panel normal direction to the light entering from a certain angle (θ=30°) was about 46%, and the maximum contrast ratio was 6 at φ=45°. As the reference, a standard white plate of MgO is used. In this graph, it is when $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda$ is ±0.25 that the reflectivity is lowered, and the maximum reflectivity is observed when the value of $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda$ is 0. By making use of these two states, a monochromatic display is achieved.

As for the setting angle, when φ=45°, the maximum contrast ratio is obtained, and the contrast ratio declines as going away from φ=45°. Practically, however, there is no problem in the range of φ=30 to 60°.

The invention relates to the case in which the value of m in the formula (4) and formula (5) is 0, but display is possible if m is 1 or more. In this case, however, the reflectivity in the light transmission state is lowered, and the reflectivity in the light shielding state is raised to the contrary, and hence the contrast ratio is lowered, and preferably it is desired to use in the condition of m = 0.

In this embodiment, as the optical phase compensator, an oriented film made of polycarbonate is used, but it is not limitative, and other oriented films of PVA (polyvinyl alcohol), PMMA (polymethyl methacrylate) and others can be used. Besides, a liquid crystal cell by parallel orientation treatment may be also used as the optical phase compensator.

· In the reflective liquid crystal display device of the invention, the side of the reflector forming reflective electrodes is disposed at the liquid crystal layer side, parallax is eliminated, and a fav rable display screen is obtained.

The inventors also confirmed that activ matrix driv is possibl by using the reflective el ctrodes as th pixel el ctrodes of thin film transistors, MIM and other nonlinear elements. Furthermore, to increase the steepness of the electro-optical characteristics, it is better to keep the retardation constant regardless of the location, but, strictly speaking, if there is a step in the reflector, the cell thickness differs between above and below the step, and hence the retardation value varies. Accordingly, the inventors formed a flattened layer made of acrylic resin on the reflector, and a transparent electrode of ITO is formed thereon as pixel electrode, and the step is controlled at 0.1 μm. Thus, it has been confirmed that the steepness of the electro-optical characteristics be enhanced outstandingly.

As the flattened layer, any transparent film possessing flattening capability, whether inorganic material or organic material, may be used. Hence, simple multiplex driving of more than 100 scanning lines can be realized.

In the embodiment, glass substrates were used, but similar effects are expected by forming active elements by opaque substrates such as silicon substrates.

As other embodiment, using the light shielding state of $(\Delta n_1 d_1 - \Delta n_2 d_2)/\lambda = 0.25$ in the case of φ=45° in the preceding embodiment, by using a phase difference plate having a wavelength dispersion larger than the wavelength dispersion of the liquid crystal, the formula (4) may be satisfied in almost all wavelengths from 400 to 700 nm. That is, as shown in Fig. 9 (a), in the light shielding state when voltage $V_1(V_1 \geq 0)$ is applied, and in the light transmitting state when voltage $V_2(V_2 > V_1)$ is applied, when the magnitude $(\Delta n\lambda)_F = (\Delta n_{400} - \Delta n_{700})/\Delta n_{550}$ of the wavelength dispersion of the substrate possessing the optical phase compensating function, and the magnitude $(\Delta n\lambda)_{LC} = (\Delta n_{400} - \Delta n_{700})/\Delta n_{550}$ of the wavelength dispersion of the liquid crystal cell satisfy the condition of $(\Delta n\lambda)_F > (\Delta n\lambda)_{LC}$ (Fig. 10 (b)), if $\Delta n_1 d_1 < \Delta n_2 d_2$ in the light shielding state (Fig. 10 (b), (c)), and when satisfying $(\Delta n\lambda)_F < (\Delta n\lambda)_{LC}$ (Fig. 10 (c)), if in the light shielding state (Fig. 10 (a)), the retardation combining the liquid crystal layer and phase difference plate can satisfy the formula (4) in a wider range of wavelength region (Fig. 10 (d)).

Similarly, in the light transmitting state when voltage $V_1(V_1 \geq 0)$ is applied and in the light shielding state when voltage $V_2(V_2 > V_1)$ is applied, the formula (4) may be satisfied in a wider range of wavelength region by satisfying $(\Delta n\lambda)_F > (\Delta n\lambda)_{LC}$ if $\Delta n_1 d_1 > \Delta n_2 d_2$ in the light shielding state and $(\Delta n\lambda)_F < (\Delta n\lambda)_{LC}$ if $\Delta n_1 d_1 < \Delta n_2 d_2$.

Fig. 11 shows the result of measuring the value of $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda$ at ach wavel ngth when using such phase difference plate. Line L11 shows the characteristics f the phase difference plate of th in-

vention, and line L12 represents the conv ntional phase difference plate. As clear from the diagram, by using the phase difference plate f the invention, the condition formula can be satisfied in almost all wavelengths from 400 to 700 nm.

Fig. 12 shows the voltage-reflectivity characteristics LA by using a phase difference plate having a larger wavelength dispersion than the wavelength dispersion of the liquid crystal, and the voltage-reflectivity characteristics LB by using a conventional phase difference plate having a smaller wavelength dispersion than the wavelength dispersion of the liquid crystal. In this case, the measuring method is same as In the preceding embodiment.

As evident from Fig. 12, when the phase difference plate having a larger wavelength dispersion than the liquid crystal layer Is used, the condition of the light shielding state can be satisfied in a wider range of wavelengths and the reflectivity of the light shielding state is lowered, so that a favorable display performance without parallax at the contrast ratio of 8 is exhibited.

That Is, when the wavelength dispersion, whose retardation in the light shielding state is smaller, is set larger than the other wavelength dispersion, it is possible to realize the desired light shielding state in wider range of wavelengths, so that the display characteristics may be enhanced.

In the embodiment, parallel orientation is used in the liquid crystal layer, but It Is not limitative, and a liquid crystal layer of any orientation can be applied as far as the retardation can be controlled by the electric field.

As the optical Phase compensator, any liquid crystal layer capable of optimally setting the retardation can be used.

The invention is not limited to the foregoing embodiments alone, but may be widely applied in reflective type optical control devices.

Moreover, by forming a color filter layer on one substrate, multi-color or full-color display may be also realized.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being Indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and the range of equivalency of the claims are therefore Intended to be embraced therein.

Claims

1. A reflective type liquid crystal display device (1) disposing a polarizer (15) at the incident sid f the liquid crystal cell (3,8,13) at which light is incident,

th liquid crystal cell (3,8,13) comprising:

an insulating substrate (3) forming at least a transparent electrode (10),

a mirror-finished light reflecting member (8) possessing smooth undulations on one surface, and forming a light reflecting surface on the same surface, and forming a counter electrode (7) for displaying and driving through collaboration with the transparent electrode (10), and

a liquid crystal layer (13) having the orientation of liquid crystal molecules (20) selected in either parallel orientation or twisted orientation, being sealed in between the insulating substrate (3) and the light reflecting member (8),

wherein an optical phase compensating member (14) is disposed between the polarizer (15) and the liquid crystal cell (3,8,13).

2. The reflective type liquid crystal display device (1) of claim 1, wherein the light transmission state Is selected when the retardation $\Delta n_1 d_1$ (Δn_1: optical anisotropy of liquid crystal layer (13), d_1: thickness of liquid crystal layer (13)) of the liquid crystal cell (3,8,13), and the retardation $\Delta n_2 d_2$ (Δn_2: optical anisotropy of optical phase compensating member (14), d_2: thickness of optical phase compensating member (14)) of the optical phase compensating member (14) are In the relation of

$$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = m/2 \pm 0.1 \ (m = 0, 1, 2, \cdots)$$
$$(1)$$

in terms of the wavelength λ in a range of 400 to 700 nm upon application of voltage V1, and the light shielding state Is selected when they are In the relation of

$$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = 0.25 + m/2 \pm 0.1 \ (m = 0, 1, 2, \cdots) \quad (2)$$

in terms of the wavelength λ in a range of 400 to 700 nm upon application of voltage V2, and the numerical value of $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda$ Is varied depending on the electric field applied to the liquid crystal layer (13).

3. The reflective type liquid crystal display device (1) of claim 1, wherein the retardation $\Delta n_1 d_1$ of the liquid crystal cell (3,8,13) and the retardation $\Delta n_2 d_2$ of the optical phase compensating member (14) are selected so as to satisfy formula (1) in terms of the wavelength λ of the light In a range of 400 to 700 nm upon non-application of voltage, and the numerical value of $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda$ is varied depending on the electric field applied to the liquid crystal layer (13).

4. The reflective typ liquid crystal display device (1) of claim 1, wh rein the retardation $\Delta n_1 d_1$ f the

liquid crystal cell (3,8,13) and the retardation $\Delta n_2 d_2$ of the ptical phase compensating m mber (14) are selected so as to satisfy formula (2) in terms of the wavelength λ of the light in a range of 400 to 700 nm upon non-application of voltage, and the numerical value of $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda$ is varied depending on the electric field applied to the liquid crystal layer (13).

5. The reflective type liquid crystal display device (1) in any one of claim 1 to claim 4, wherein the light reflecting film (7) forming the light reflecting surface of the light reflecting member (8) confronts the liquid crystal layer side.

6. The reflective type liquid crystal display device (1) of claim 1, wherein the light reflecting surface is determined as an electrode surface confronting the transparent electrode (10) formed on the insulating substrate (3).

7. The reflective type liquid crystal display device (1) of claim 1, wherein the optical phase compensating member (14) is a liquid crystal cell comprising a pair of transparent substrates, transparent electrodes formed on the transparent substrates, and a liquid crystal layer inserted between the transparent substrates.

8. The reflective type liquid crystal display device (1) of claim 1, wherein the optical phase compensating member (14) is a high molecular oriented film.

9. The reflective type liquid crystal display device (1) of claim 1, wherein a transparent flattened layer (6) for absorbing the undulations formed on the surface of the light reflecting member (8) is disposed on the light reflecting surface, and transparent electrodes (7) are formed on this flattened layer, and these transparent electrodes (7) are determined as the electrodes confronting the transparent electrodes (10) formed on the insulating substrate (3).

10. The reflective type liquid crystal display device (1) of claim 1, wherein a color filter layer is formed on either the insulating substrate (3) or the transparent electrode (10) formed on the insulating substrate (3).

11. A reflective type liquid crystal display device (1) comprising an insulating light transmittable substrate (3) forming at least a transparent electrode (10), a reflector (8) possessing smoothly and continuously changing undulations on one side and forming a thin film (7) possessing a light reflection function on the ame surface, a liquid

crystal cell (3,8,13) possessing a liquid crystal layer (13) inserted betw en the light transmittable substrate (3) and reflector (8), a polarizer (15) disposed at the light incident side, and a substrate (14), possessing an optical phase compensating function being disposed between the polarizer (15) and liquid crystal cell (3,8,13), wherein

the director direction of the liquid crystal molecule (20) of the liquid crystal cell (3,8,13) is almost orthogonal to the slow direction of the substrate (14) possessing the optical phase compensating function,

the value of $|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda$ is varied by the electric field applied to the liquid crystal layer (13) so as to establish the light shielding state when the retardation $\Delta n_1 d_1$ of the liquid crystal cell (3,8,13) and the retardation $\Delta n_2 d_2$ of the substrate (14) possessing the optical phase compensating function satisfy the formula, and

$$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = m/2 \pm 0.1 \ (m = 0, 1, 2, \cdots) \quad (1)$$

the light shielding state when they satisfy the formula,

$$|\Delta n_1 d_1 - \Delta n_2 d_2|/\lambda = 0.25 + m/2 \pm 0.1 \ (m = 0, 1, 2, \cdots) \quad (2)$$

thereby displaying by making use of these two states, and moreover the absorption axis or transmission axis of the polarizer (15) is set in a range of 30° to 60° to the director direction of liquid crystal molecule (20) of the liquid crystal cell (3,8,13).

12. The reflective type liquid crystal display device (1) of claim 11, wherein it is the light shielding state when the retardation $\Delta n_1 d_1$ of the liquid crystal cell (3,8,13) and the retardation $\Delta n_2 d_2$ of the substrate (14) possessing the optical phase compensating function satisfy the formula (2) for a certain wavelength λ in a range of 400 to 700 nm when voltage $V_1(V_1 \pm 0)$ is applied, and the light transmitting state when they satisfy the formula (1) for a certain wavelength λ in a range of 400 to 700 nm when voltage $V_2(V_2 > V_1)$ is applied,

the relation is $(\Delta n\lambda)_F > (\Delta n\lambda)_{LC}$ when the magnitude $(\Delta n\lambda)_F$ of wavelength dispersion of the substrate (14) possessing the optical phase compensating function and the magnitude $(\Delta n\lambda)_{LC}$ of wavelength dispersion of the liquid crystal cell (3,8,13) satisfy the condition of $\Delta n_1 d_1 > \Delta n_2 d_2$ in the light shielding state, and

it is $(\Delta n\lambda)_F < (\Delta n\lambda)_{LC}$ when satisfying the condition of $\Delta n_1 d_1 < \Delta n_2 d_2$ in he light shielding state.

13. The reflectiv typ liquid crystal display device (1) of claim 11, wherein it is the light transmitting state when the retardation $\Delta n_1 d_1$ of the liquid

crystal cell (3,8,13) and the retardation $\Delta n_2 d_2$ of th substrat (14) possessing the ptical phas compensating functi n satisfy the formula (1) for a certain wavelength in a range of 400 to 700 nm when voltage $V_1(V_1 \pm 0)$ is applied, and the light shielding state when they satisfy the formula (2) for a certain wavelength in a range of 400 to 700 nm when voltage $V_2(V_2 > V_1)$ is applied,

the relation is $(\Delta n\lambda)_F > (\Delta n\lambda)_{LC}$ when the magnitude $(\Delta n\lambda)_F$ of wavelength dispersion of the substrate (14) possessing the optical phase compensating function and the magnitude $(\Delta n\lambda)_{LC}$ of wavelength dispersion of the liquid crystal cell (3,8,13) satisfy the condition of $\Delta n_1 d_1 > \Delta n_2 d_2$ in the light shielding state, and

it is $(\Delta n\lambda)_F < (\Delta n\lambda)_{LC}$ when satisfying the condition of $\Delta n_1 d_1 < \Delta n_2 d_2$ in the light shielding state.

14. The reflective type liquid crystal display device (1) of claim 11, 12 or 13, wherein the reflective film (7) forming plane of the reflector (8) is disposed at the liquid crystal layer side.

15. The reflective type liquid crystal display device (1) of claim 11, 12, 13 or 14, wherein the thin film (7) possessing the light reflecting function of the reflector functions also as the electrode confronting the transparent electrode (10) formed on the light transmittable substrate (3).

16. The reflective type liquid crystal display device (1) of claim 11, 12, 13, 14 or 15, wherein a transparent flattened layer (6) for absorbing undulations is provided on the thin film (7) possessing the light reflecting function, and a transparent electrode (7) is formed thereon so as to function as the electrode (7) confronting the electrode (10) formed on the light transmittable substrate (3).

17. The reflective type liquid crystal display device (1) of claim 11, 12, 13, 14, 15 or 16, wherein a color filter layer is formed on the surface or transparent electrode (10) of the light transmittable substrate (3).

5

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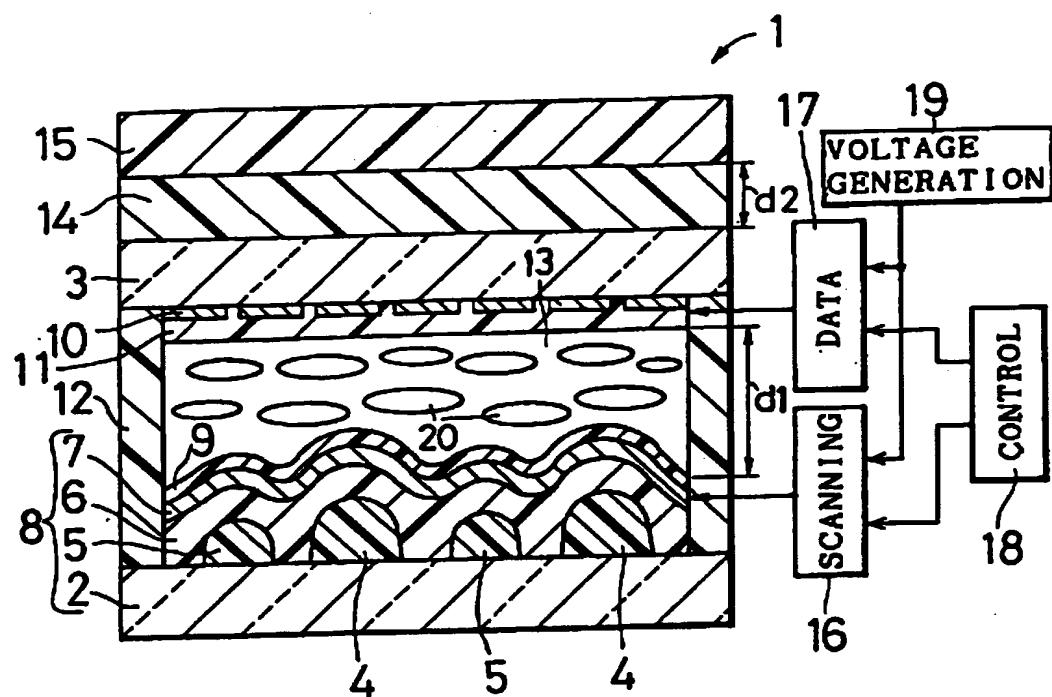
Fig. 1

Fig. 2

Fig. 3

Fig.4(1)

Fig.4(2)

EXPOSURE
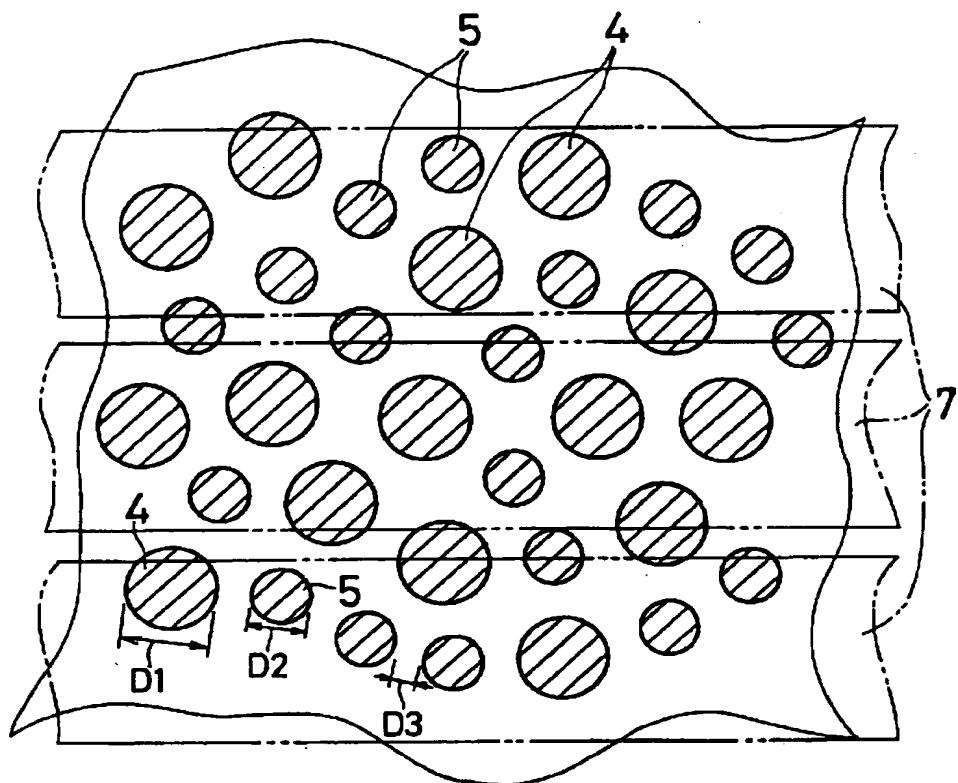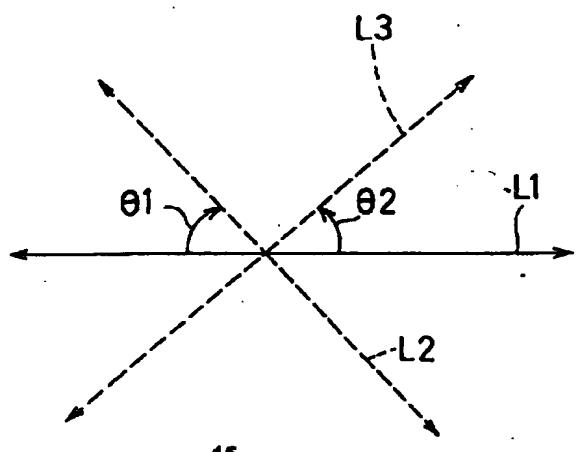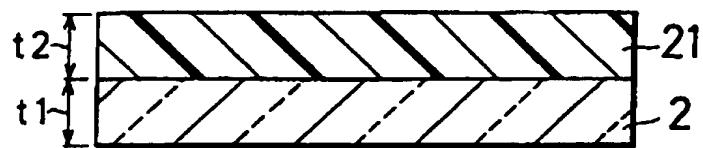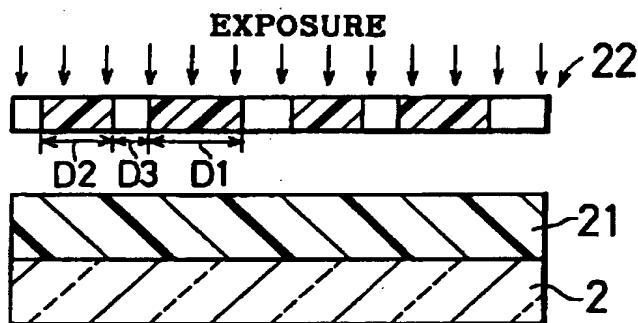
Fig.4(3)
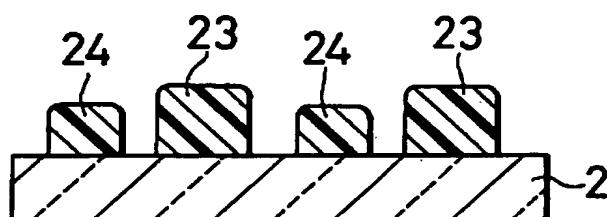
Fig.4(4)
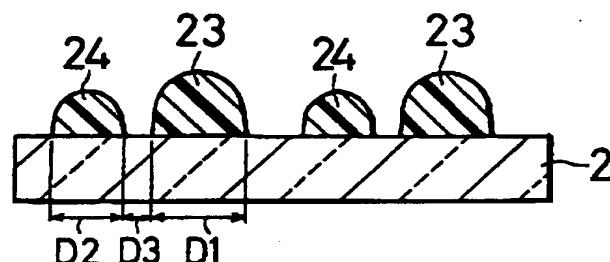
Fig.4(5)
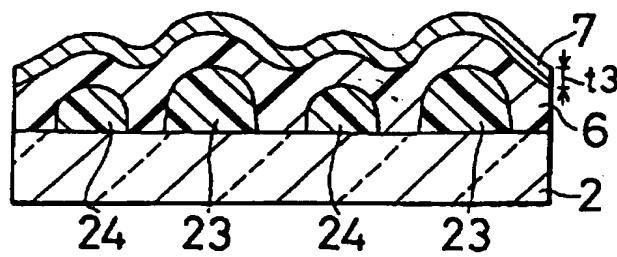
Fig. 5
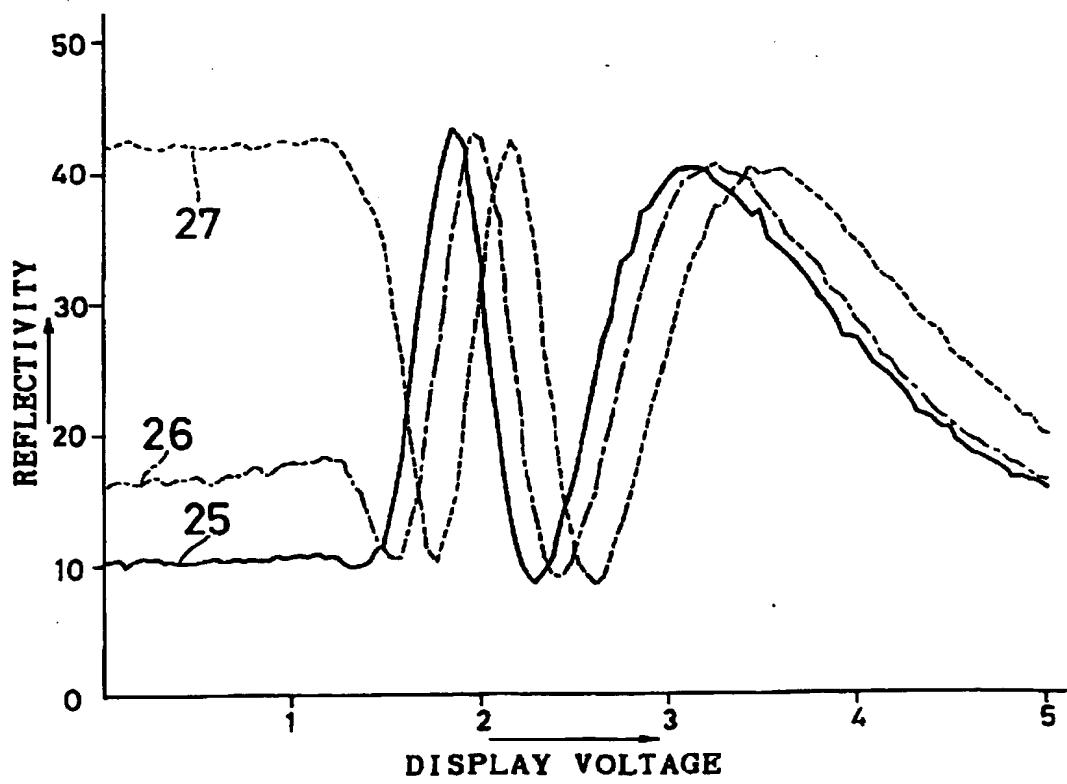
Fig. 6 (1)
(SHIELDING
REFLECTED LIGHT)
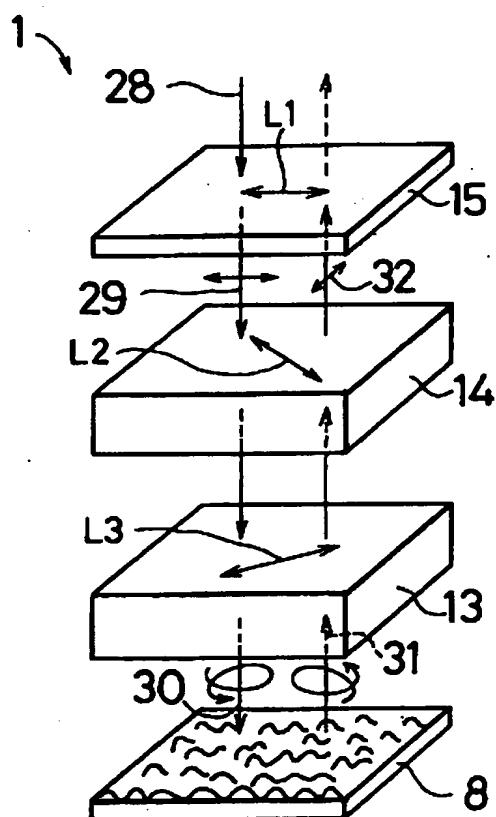
Fig. 6 (2)
(TRANSMITTING
REFLECTED LIGHT)

Fig. 7

Fig. 8

Fig.9(a)

REFLECTIVITY R (%)

$0 \leqq V1 \leqq V2$

APPLIED VOLTAGE V (V)

Fig.9(b)

$\Delta nd(\lambda=550nm)$

OPTICAL PHASE COMPENSATOR

LIQUID CRYSTAL LAYER

V1 V2

VOLTAGE V (V)

Fig.9(c)

$\Delta nd(\lambda=550nm)$

OPTICAL PHASE COMPENSATOR

LIQUID CRYSTAL LAYER

V1 V2

VOLTAGE V (V)
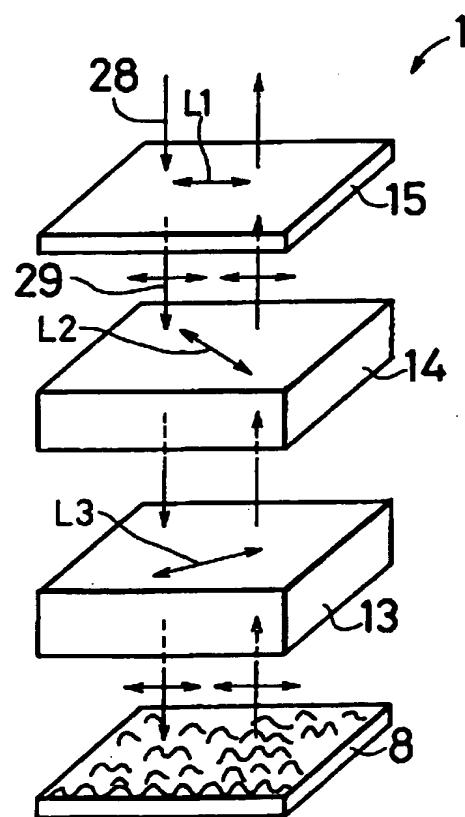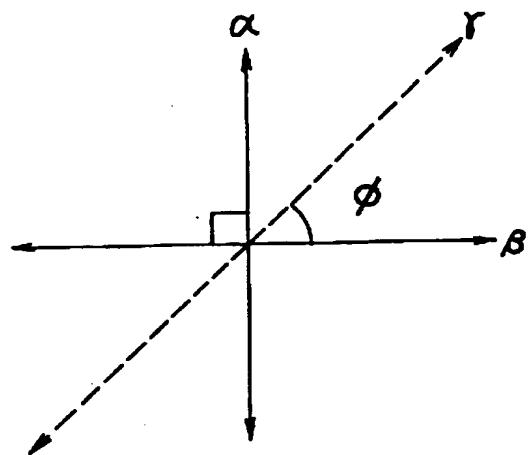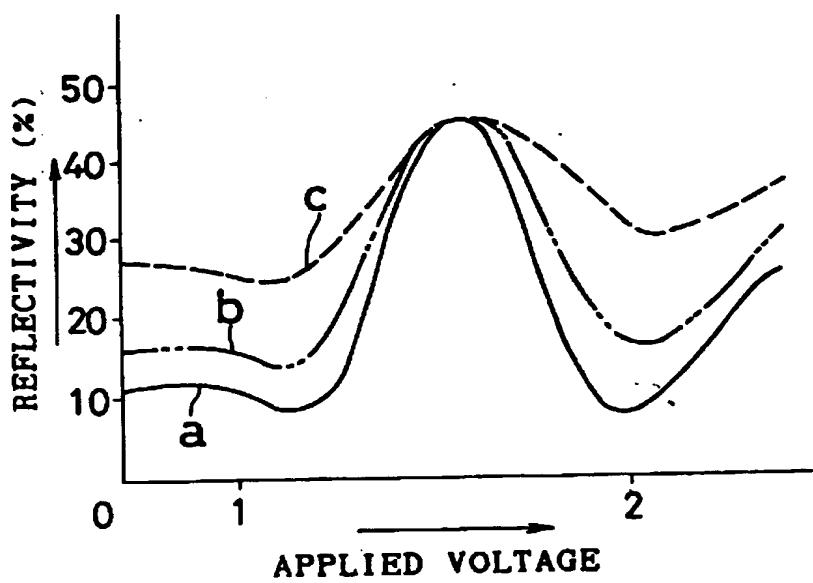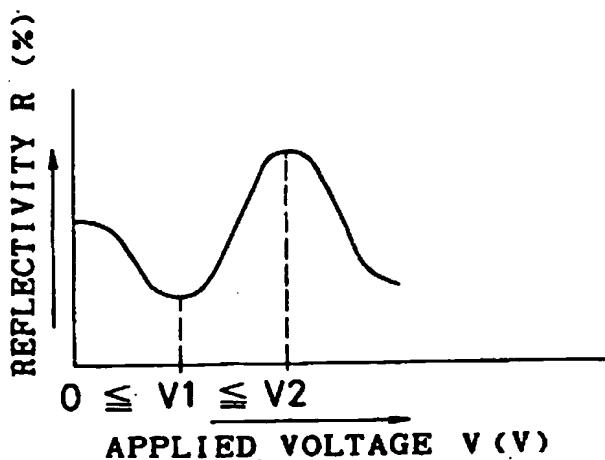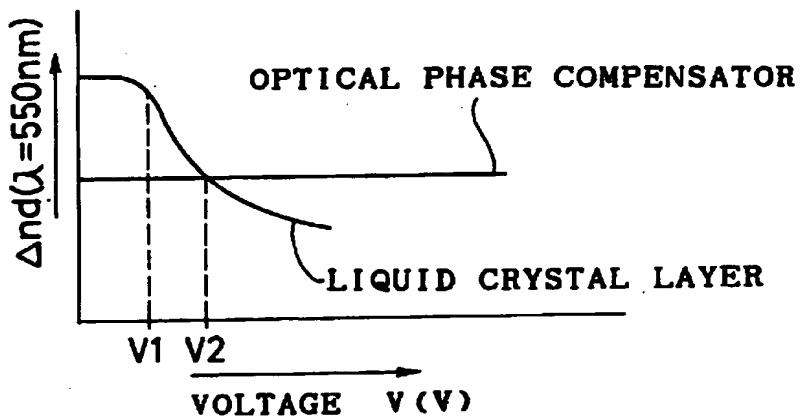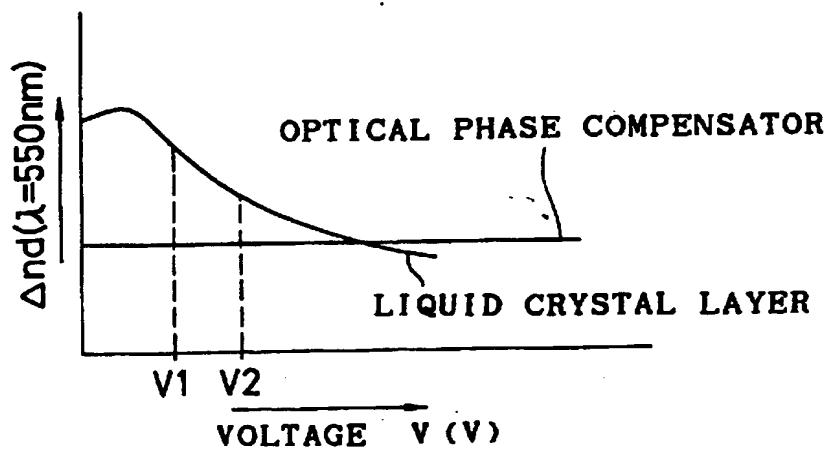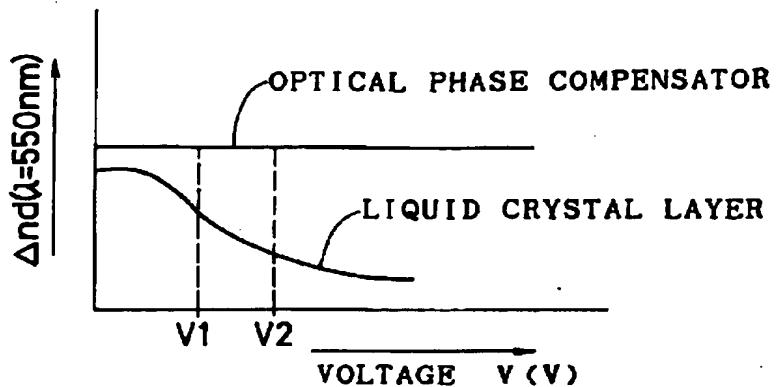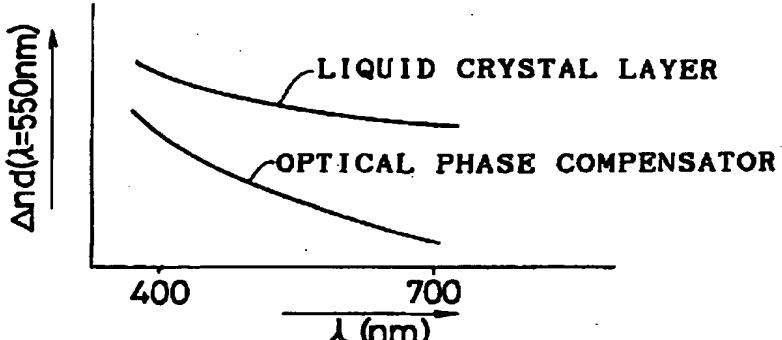
Fig.10(a)
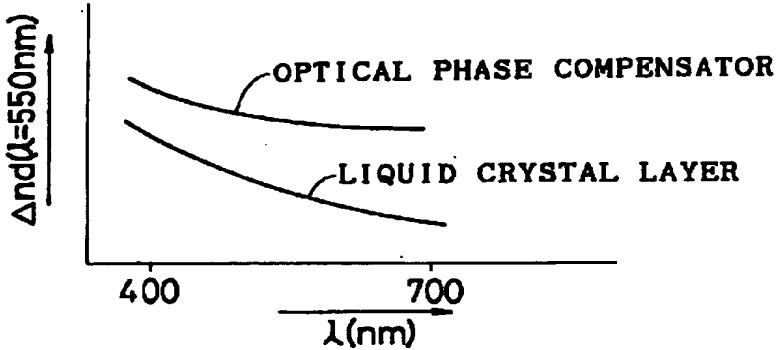
Fig.10(b)

Fig.10(c)

Fig.10(d)
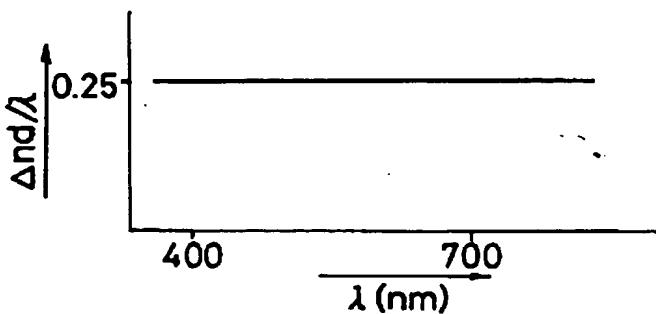
Fig.11
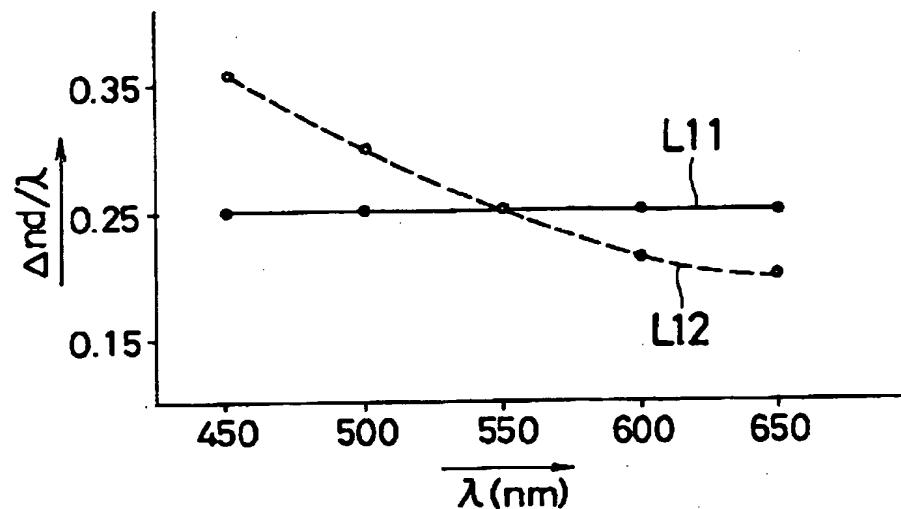
Fig.12
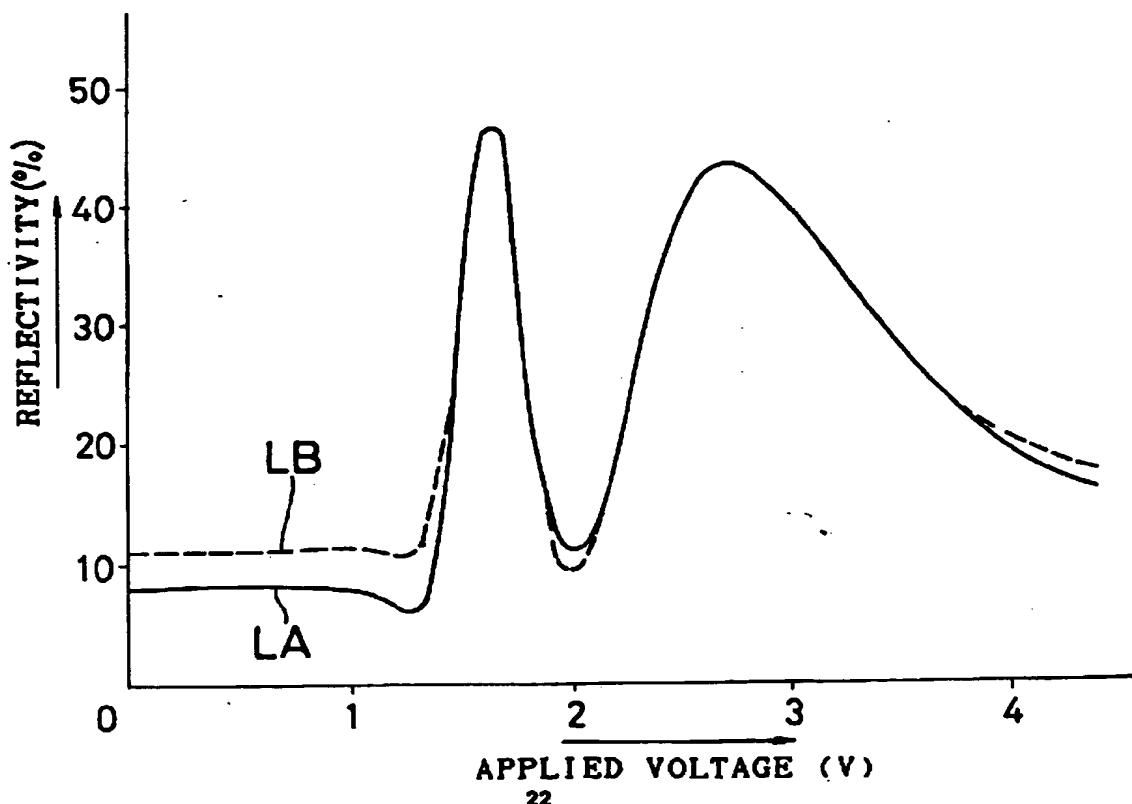
European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP   93 30 5026

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	EP-A-0 470 817 (SEIKO) * column 9, line 3 - column 11, line 6 * * claim 10; figures 15-18 *	1,5-6,8	G02F1/1335
A	idem	11,14-15	
A	EP-A-0 467 659 (SHARP) * abstract * * column 6, line 11 - line 26 * * claims 1-4; figures 6,8 *	1,5-6, 10,11, 14-15,17	
A	EP-A-0 162 775 (C.E.A.) * page 13, line 1 - page 15, line 20 * * claims 1,5-8; figure 8 *	1,5-8, 11,14-15	
D	& US-A-4 701 028 (J.F. CLERC ET AL.)		
A	PATENT ABSTRACTS OF JAPAN vol. 6, no. 75 (P-114)12 May 1982 & JP-A-57 013 422 (SUWA SEIKOSHA) 23 January 1982 * abstract *	9,16	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G02F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30 SEPTEMBER 1993	IASEVOLI R.

EPO FORM 1503 03.82 (P0401)